ELSEVIER
Available online at www.sciencedirect.com
SCIENCE DIRECT
Vision Research 46 (2006) 2525–2534
Vision Research
www.elsevier.com/locate/visres

Biases in judgments of separation and orientation of elements belonging to different clusters

Tatjana Seizova-Cajic [a,*], Barbara Gillam [b]

[a] *University of Sydney, Australia*
[b] *University of New South Wales, Australia*

Received 26 September 2005; received in revised form 22 December 2005

Abstract

If two demarcated dots are embedded in separate clusters of similar dots in off centre positions, their perceived separation is biased towards the separation between the centres of the clusters (Morgan, Hole, & Glennerster, 1990). We replicated these results and went on to determine whether a similar bias is present for orientation judgments, using a staircase method and a range of cluster orientations and separations. A complex pattern of biases was found including biases for targets at centroids. Orientation attraction towards tangents to the clusters seemed to be involved. We conclude that orientation is subject to different contextual constraints from separation, and that bias towards the edges of clusters needs to be included in models of position coding.

Keywords: Bias; Geometrical illusion; Centroid; Orientation; Separation

1. Introduction

The relative position of two points can be specified by two parameters: their collinear separation, and their orientation relative to a reference orientation (e.g., the horizontal). Context may influence the perception of separation creating illusory biases. The Muller-Lyer illusion is an example of this.

Morgan, Hole, and Glennerster (1990) attempted to explain the Muller-Lyer and related illusions using a model of position coding developed by Watt (1988). Watt was motivated by computational considerations, namely the high cost of representing the position of each distinguishable element relative to every other one. He proposed a hierarchical scheme in which the positions of groups of elements are encoded directly relative to each other whereas the positions of individual elements are coded only in relation to their group, and not directly in relation to each other. Watt suggested this as an effective solution to position coding especially when the position of groups rather than elements is an acceptable approximation, and when the positions of elements within a group (e.g., the positions of the eyes on a face) rather than between groups are important.

If groups are coded directly relative to each other the issue arises as to how the position of a group is represented. Morgan et al. (1990; see also Harris and Morgan, 1993, Morgan and Glennerster, 1991) argue that the visual system automatically extracts the position of the centroid[1] and uses it to compute group position relative to other groups. The position of elements belonging to different groups is derived from their position relative to the centroid of their object, and from the separation between the centroids of the two objects. The crucial aspect of this proposal is that indirect coding of the position of points that belong to different

* Corresponding author.
E-mail address: tanjas@psych.usyd.edu.au (T. Seizova-Cajic).

[1] Centroid is centre of mass. For thin objects with uniform thickness, if they have a geometrical centre, that point will also be their centroid (Gullberg, 1997). For example, the centroid of a rectangle is the point of intersection of its diagonals. In computations of a centroid of the lightness distribution of a 2-D image, the elements or areas of the surface are weighed differently depending on their lightness values.

0042-6989/$ - see front matter
doi:10.1016/j.visres.2006.02.010

objects can result in a bias. “The visual system has a strictly limited ability to extract the position of parts of objects independently of immediately surrounding parts, even if it can be visually resolved from them” (Morgan et al., 1990, p. 1800). It is hypothesised that the Muller-Lyer and similar illusions may be a consequence of this limitation, since the visual system is maladapted to estimate the separation between any two arbitrarily chosen points. This proposal is similar to Woodworth’s (1945, p. 460), who said that, in an attempt to compare the shafts of the Muller-Lyer figures, one is “more likely to take the whole figure in the rough and to compare the distances between the main masses.”

Morgan et al. (1990) tested their claim regarding centroid bias using a pair of dots as stimuli. Each of these test dots was embedded in a cluster of dots of the same shape but a different colour (see Fig. 1). The test dots were placed either at the centre of the respective clusters or at various positions off centre. Participants were required to judge the separation between these dots relative to the standard separation between a plain pair of dots, while ignoring the clusters. The test and comparison dots were presented sequentially so that it is possible that any centroid bias was influenced by memory as well as perception. The results did provide evidence of a centroid bias, i.e., separation judgments for a pair of dots were biased towards the centres of the clusters in which the dots were embedded.

It seems clear from the theory that a centroid bias in the perceived position of target dots embedded eccentrically in dot clusters, should also introduce a bias in the perceived orientation of the pair since the bias is considered to be a result of a requirement for efficient coding. Morgan et al. (1990) did not discuss centroid bias in relation to perceived orientation. However, a study by Gillam and Chambers (1985) indicates that such a bias may not exist. Observers in this study were asked to vertically align a point with the apex of the Muller-Lyer figure (see Fig. 2). They were highly accurate in positioning the dot, while exhibiting the usual illusory effect in a concurrent length-matching task. Thus the same context that resulted in misperception of separation between the vertices did not cause misperception

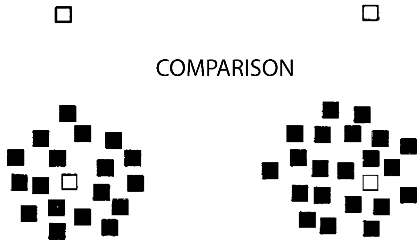

Fig. 1. Stimulus arrangement used in Morgan et al’s experiment. The observer’s task was to compare the distance between the two white squares (green in the study) in the comparison stimulus with the distance between the squares in the standard stimulus. The position of the green squares in the cluster was varied to determine its effect upon the perceived separation of the green squares. (Fig. 5 from Morgan et al., 1990).

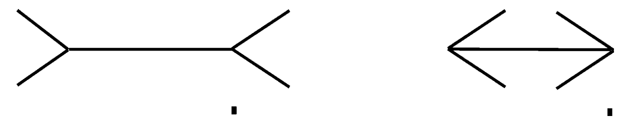

Fig. 2. Stimuli used in the study by Gillam and Chambers (1985). See text for details.

of the relationship of the vertices and points below them. Gillam & Chambers concluded that perceived size did not depend on position coding. In commenting on Gillam & Chambers’ result Morgan et al. (1990) themselves comment that “it is logically quite possible that the correct position of the vertex is accessible to orientationally-tuned mechanisms, but not to spatial-interval mechanisms” (p. 1799). On the other hand, their functional account of centroid bias seems to imply that orientation should be affected in a similar way as separation.

The main goal of this study is to test the latter possibility. The study has two parts, one concerned with perceived separation, and the other with perceived orientation. Experiment 1 is an attempt to replicate the results of Morgan et al. (1990) regarding separation. However simultaneous rather than successive presentation of the standard and the comparison stimuli was used to ensure that any effect of centroid bias is not attributable to memory. In Experiment 2 and 3, a similar experimental paradigm was used to determine whether there is also a centroid bias in perceived orientation.

2. Experiment 1

2.1. Method

2.1.1. Stimuli and procedure

The method was similar to that used by Morgan et al. (1990). A dot was presented in each of two clusters. The position of the clusters varied, such that each was either centred on the dot, or displaced by various amounts (referred to as ‘offset’). A staircase method was used to measure the perceived separation of the dots. Participants had to decide on a given trial whether the separation in the comparison stimulus was smaller or larger than in the standard. The standard stimulus consisted of clusters in which targets were embedded, and the comparison stimulus were two plain dots (see Fig. 3).

Cluster diameter was 18 mm, subtending a visual angle of 1.72 at the 60 cm viewing distance, and all the dots were squares with 1.5 mm sides. The distance between the target dots was constant within each staircase, and it was either 45 or 65 mm. The step size was 0.6 mm, and presentation time was 4 s. Stimuli were presented on a Macintosh computer (Imac G4) with a 15″ flat screen monitor, with resolution set to 1024×768. The experiment was performed in an experimental room with natural daytime illumination.

Positions of the standard and the comparison were, independently of each other, varied from trial to trial to discourage attempts to use extraneous cues. Direction and

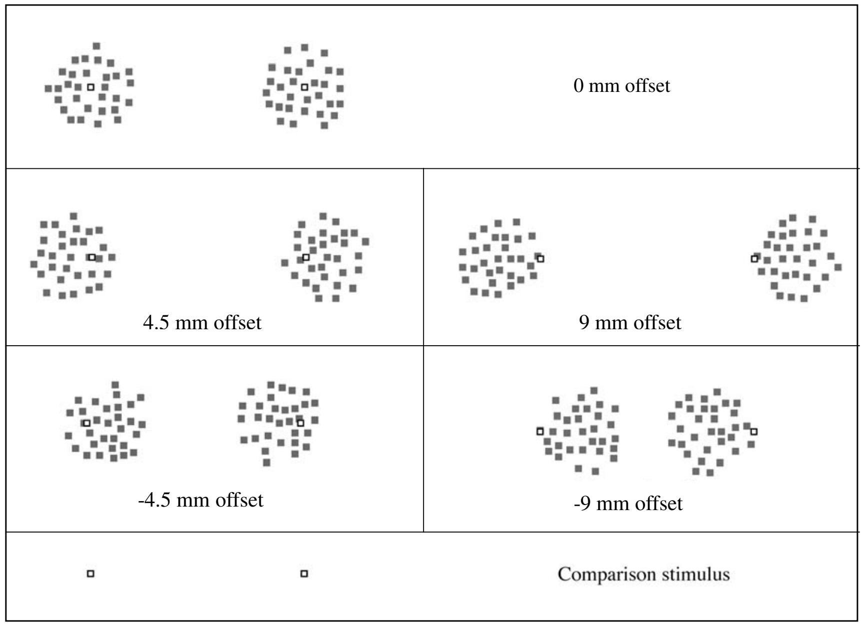

Fig. 3. Standard and comparison stimuli used in Experiment 1 (45 mm condition; 65 mm condition not shown), drawn to scale. Note that only the separation between the clusters varies, while the separation between the target dots (unfilled squares) is the same in each pair, including the comparison stimulus (the latter of course varied in the experiment itself). The distribution of the other dots ($n = 30$) was randomised in each presentation. In the experiment itself, target dots were blue, and other dots red, and they were presented on the white background.

amount of jitter was randomly determined from within a ±14 mm range of the original position. Each experimental run consisted of four interleaved staircases. Cluster offset was the same in all four staircases, but two of them had a 45 mm dot separation and two had a 65 mm dot separation. For each separation there was one ascending and one descending staircase. Each staircase was terminated after 15 reversals, and the whole run took about 20 min to complete. Participants were instructed to ignore the clusters and pay attention to the dots. They completed a practice run with feedback before the experiment.

2.1.2. Participants

Five participants completed the experiment. Four were undergraduate students fulfilling their course requirement, and one (CL) was a member of the lab. The students were naïve with respect to the goal of the study, and all participants had self-reported normal or corrected to normal vision.

2.2. Results

Bias was defined as the difference between the standard and the comparison stimuli at the point of reversal. Mean bias was calculated by averaging across all 30 reversals (15 descending and 15 ascending) for a given standard separation. For each participant, the response bias in the baseline condition (plain dots) was subtracted from all other data points for the given condition. Means obtained in this way were used as basic units in the analyses presented below.

Individual data for separation judgments are presented in Table 1. The responses in the two separation conditions show a similar pattern. There is a clear although not very large effect of context on perceived separation. When the dots are closer to the outer edges of the clusters, their separation is underestimated, and when they are closer to the inner edges, it is overestimated. The latter effect is stronger than the former.

Table 1
Bias as a function of cluster offset, individual results

	−9 mm	−4.5 mm	0 mm	4.5 mm	9 mm
45 mm standard separation					
CA	−5.76	−1.98	0.15	3.88	4.39
CL	−1.98	−0.08	3.32	2.74	1.74
DA	−3.57	−3.12	−1.04	−0.96	−0.74
EM	−2.10	1.35	−0.55	1.75	5.54
JU	−4.61	−4.46	−0.53	2.61	3.39
Means	−3.60	−1.66	0.27	2.00	2.86
65 mm standard separation					
CA	−5.32	−3.85	−1.73	1.25	5.65
CL	−2.97	−0.13	−0.34	2.40	2.53
DA	−2.93	−2.09	−0.63	2.24	2.49
EM	−3.39	−1.46	−1.67	1.06	7.09
JU	−8.09	−5.98	−0.91	2.53	3.65
Means	−4.54	−2.70	−1.06	1.90	4.28
Max. exp. bias	−18	−9	0	9	18

Positive numbers indicate overestimation, and negative numbers, underestimation.

A 2-way ANOVA was performed on the individual data (30 reversal points per condition) for each of the five participants. The factors in the ANOVA were separation (45 and 65 mm) and Cluster offset (−9, −4.5, 0, 4.5 and 9 mm). The main effect of Cluster offset was highly significant for each participant (the smallest $F(4,26)$ was 164; $p < 0.001$), and so was the effect of Separation ($F(1,29) > 33$; $p < 0.001$). The interaction between the two was also significant ($F(4,26) > 21$; $p < 0.001$), reflecting the fact that the 65 mm condition resulted in a larger bias for positive cluster offsets, and the 45 mm condition, for negative offsets.

Note also that responses in the zero-offset condition—when targets were placed at cluster centroids—are not bias-free. Most participants underestimated the separation in that condition, and one participant overestimated it by about 7% (CL, 45 mm condition; this run was replicated several weeks later, with the almost identical result). One-sample *t*-tests performed on individual data for 45 and 65 mm conditions separately showed that in all cases, the PSE was significantly different from zero (df = 29; *t*-values ranged from −18.7 to +23.32; $p < 0.01$, except in one case, where $p < 0.03$).

Our results confirm Morgan et al's results. However since simultaneous presentation of the standard and comparison stimuli was used, memory was ruled out as a major factor. The results are consistent with the centroid bias (Morgan et al., 1990) or 'main masses' hypothesis (Woodworth, 1945) advanced to account for the Muller-Lyer illusion and its variants. The combined bias for the −9 and 9 mm conditions is about 14% for the 45 mm separation and about 13% for the 65 mm separation—smaller than is typically found in Muller-Lyer experiments. There is no advantage for the condition in which the target dots were inside the centre of the cluster (positive cluster offsets) over the condition in which the dots were outside the centre of the cluster (negative offsets). This differs from the Muller-Lyer illusion for which the ingoing arrowhead condition typically gives a much larger effect that the outgoing arrowhead condition (Binet, 1895; Erlebacher & Sekuler, 1974; Fisher, 1968; Heymans, 1896).

3. Experiment 2

3.1. Method

Experiment 2 was conducted to see if there was a centroid bias in orientation using the same dot patterns as in Experiment 1. The standard pair of dots was inclined relative to the horizontal by either 10° or 30° degrees, and the collinear separation between them was either 45 or 65 mm (the 45 mm condition is shown in Fig. 4). The clusters were either centred on the dots or were shifted vertically (in the opposite directions to each other) to create offsets of ±4.5 and ±9 mm. Participants were asked if the comparison dots were more or less inclined relative to the target dots.

Four interleaved staircases were used in this experiment as well, and each was terminated after no fewer than eight reversals (five participants completed 15 reversals per staircase). The staircases differed with respect to: (a) the orientation between the standard pair of dots; it was either 10° (left dot down relative to the horizontal) or 30°, and (b) the initial orientation of an imaginary line connecting the target-dots; it was inclined either less than the standard ('descending' staircase), or more ('ascending' staircase). Five different cluster offsets and the plain dot condition were presented separately, one in each run, as well as different separations (45 mm vs. 65 mm), making a total of 12 experimental runs per subject (see Table 2). All other aspects of the method were the same as used in Experiment 1.

Nine people took part in the experiment, including CL who also participated in Experiment 1. The new participants were psychology undergraduates fulfilling their course requirement.

3.2. Results

As in Experiment 1, bias was defined as the difference between the standard and the comparison stimuli at the point of reversal, and the response bias in the baseline condition (plain dots) was subtracted from all other data points for the given condition. Group means and 95% confidence intervals for eight participants (10° orientation condition) or nine participants (30° orientation condition) are shown in Fig. 5. Note that cluster offsets and bias are expressed in millimetres (rather than in degrees), as the difference along the vertical dimension between the dots in the standard and the comparison stimulus. This was done to simplify the plots; cluster offsets expressed in millimetres are the same for different separations and orientations between the targets, but they vary by several units if expressed in degrees. Maximal expected centroid bias is twice the cluster offset in any given condition (for example, maximal expected bias for the −9 mm cluster offset condition is −18 mm, and for 9 mm offset, 18 mm).

3.2.1. The effect of cluster offset

Like separation judgments, orientation judgments in the zero-offset condition are not bias-free. In two out of four zero-offset conditions—65 mm separation, 10° and 30° orientations—there is a significant counter clockwise bias (this is indicated by the fact that the corresponding 95% confidence intervals shown in Fig. 5 do not include zero).

Significant biases are also found in conditions where cluster centres are displaced from the targets. They have a negative sign as well, that is, counter clockwise direction. Some are consistent with the centroid bias hypothesis (30° orientation, −9 mm cluster offset) but others are in the opposite direction, away from the centroid (10° orientation, +4.5 and +9 mm cluster offset).

If we consider the pattern of results, rather than only absolute bias values, it shows a consistent trend across both 45 and 65 mm separations, and a different one for the two orientations. The largest biases in the 10° condition are found for positive cluster offsets, and they are away from the centroid. In contrast, the largest bias in the 30° condition is for negative cluster offsets, and it is towards the centroid. This is illustrated in Fig. 6, which shows pairs of stimuli that create an illusion of orientation; one shows a bias away from centroids (upper panel, 10° dot orientation), and the other, the centroid bias (lower panel, 30° dot orientation).

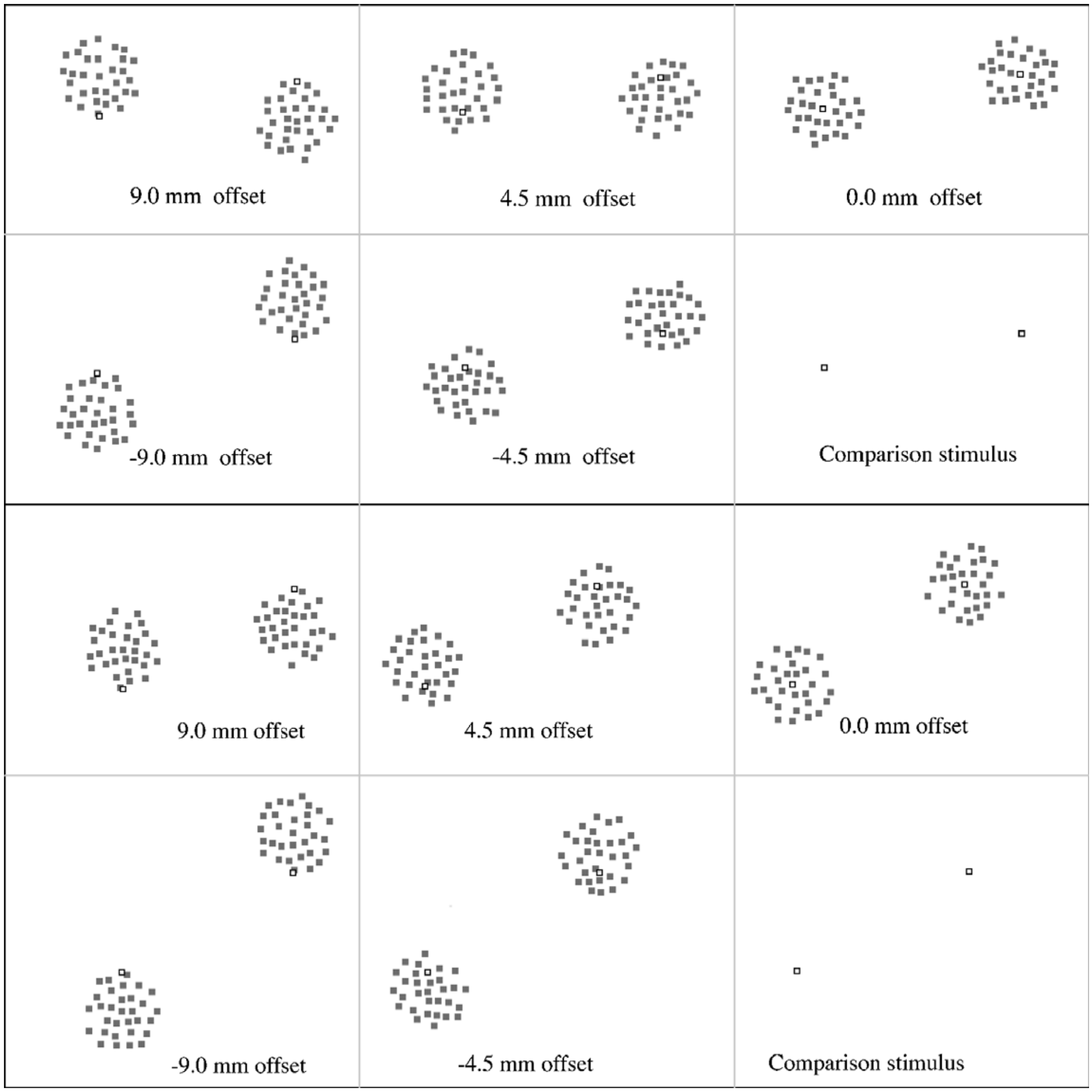

Fig. 4. Standard and comparison stimuli used in Experiment 2, drawn to scale (45 mm separation condition; 65 mm condition not shown). Target dots are represented as unfilled squares. Note that within each condition orientation between the targets is constant but the clusters were shifted one up and one down to create offsets of ±4.5 and ±9 mm. Upper panel, 10° condition. Lower panel, 30° condition. Comparison stimuli are here shown in the same orientation as the standard, but their orientation in the experiment of course varied.

Table 2
Design of experiment 2

Separation between the dots	45 or 65 mm					
Orientation between the dots	10° or 30°					
Cluster offset (mm offset along the vertical)	−9.1	−4.5	0	4.5	9	No clusters

Negative cluster offsets indicate their clockwise orientation relative to the orientation between the dots (see Fig. 4).

If the main source of bias were the internal relationship between the target dot and the centre of its cluster (as proposed by Morgan et al., 1990), then the amount of bias would only be affected by cluster offset, and not by the orientation between the target dots and the accompanying clusters. The fact that the overall configuration does have an effect suggests that the clusters *as a pair* influence orientation judgments. It suggests that the two clusters are perceived as a pair and that the orientation between them—their centroids or else the tangents to the upper or lower edges—interacts with the orientation between the target dots resulting in a bias.

Although there appeared to be a systematic effect of orientation of cluster pairs in this experiment, its precise nature was difficult to determine because many different orientations were used (remember that position of target dots was fixed at 10° and 30° and clusters moved up and down relative to them). In Experiment 3, only two cluster orientations were used, and position of dots within them varied. This should make it easier to find systematic biases due to cluster orientation.

4. Experiment 3

Reference orientation relative to which other orientations are judged and biased towards could be determined

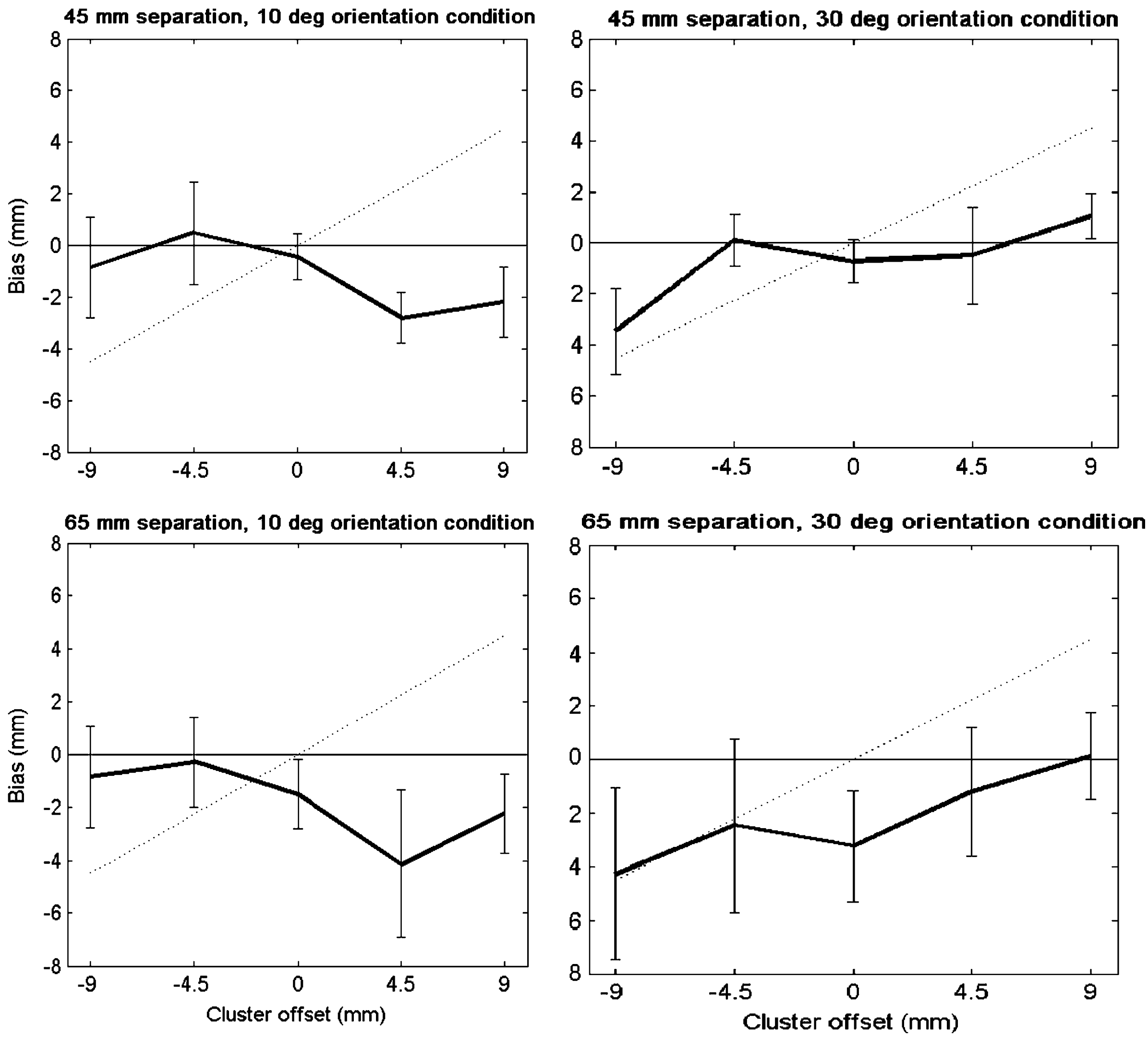

Fig. 5. Results of Experiment 2, group means and 95% confidence intervals. Positive data points indicate clockwise bias and negative, a bias in the opposite direction. The dashed line represents a bias in the expected direction, towards the centroid (only a quarter of the maximal expected bias is shown).

by the position of centroids of the two clusters, or else by the position of their edges relative to one another. Fig. 7 illustrates three potential reference orientations, one defined by the centroids and two specified by tangents to cluster edges. The question we address in this experiment is which one of them, if any, best predicts the bias in judgment of elements belonging to the clusters. For example, if there is a bias towards tangent A, then for all positions of target dots, the bias should be counter clockwise but varying in degree. The exception is a pair of targets located on cluster edges near the tangent, which should produce a zero or near-zero bias. Bias towards tangent B should give the opposite pattern of results.

4.1. Method

A pair of clusters was presented with either a 10° or a 30° orientation between cluster centroids, at 65 mm separation. Target dots were displaced up or down relative to cluster centres to obtain the same offsets between cluster centres and targets as in Experiment 2: −9, −4.5, 0, 4.5 and 9 mm (recall however that in Experiment 2, the same offsets were achieved in a different way—by displacing the clusters around fixed dots, rather than dots within the fixed clusters as here). This resulted in 10 different dot orientations (2 cluster orientations × 5 offsets). Ten corresponding plain dot conditions were included in the experiment to serve as a baseline. Other aspects of the method were the same as in Experiment 2. Six undergraduate students and the first author completed the experiment.

4.2. Results

The results were analysed in the same way as in Experiment 2. Group means and 95% confidence intervals for seven participants are shown in Fig. 8. Predictions based on the tangents and centroid reference orientations are also shown. They are based on the assumption that judgments of orientation between the targets would be biased *towards* the reference orientation. Each theoretical line shows only a

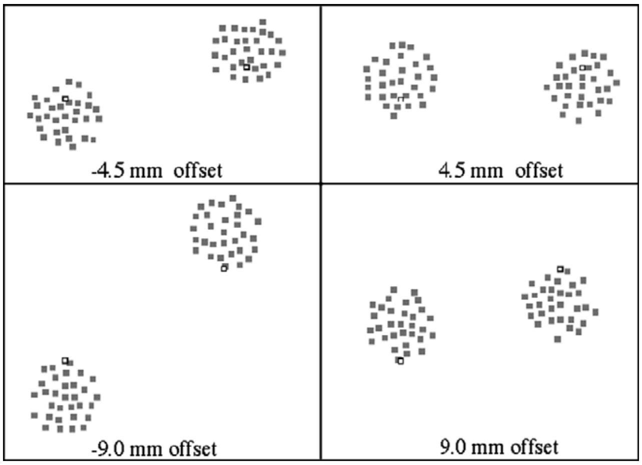

Fig. 6. Illusions of orientation in stimuli from Experiment 2. Two pairs of unfilled dots on top both have a 10° orientation relative to horizontal, and the pairs below both have a 30° orientation. However, according to our results, the unfilled dots in the top left pair appear less tilted than those on the right; note that the centroid bias hypothesis would predict an effect in the opposite direction. In the lower panel, the tilt of the left pair appears larger than the tilt of the right pair, consistent with the centroid bias proposal.

quarter of the maximal possible bias towards a particular orientation. The maximal possible bias would occur if orientation between the target dots were erroneously perceived as the reference orientation itself.

For most offsets, mean group biases are not significantly different from zero. Exceptions are two means, one in a zero-offset condition, and the other for the +9 mm offset (30° condition). The latter is predicted by the centroid bias hypothesis, but the former is not.

None of the theoretical predictions by itself gives a good fit to the results. However, there is a tendency in the results on each side of the zero-offset to follow predictions based on tangent. Consider offsets of +4.5 and +9 mm in Fig. 8; since positive offsets indicate that dots are oriented counterclockwise relative to the centroids, position of these dots is close to the tangent A in Fig. 7. Prediction based on the bias towards tangent A is shown by squares, and the two data points follow this prediction closely. Confidence intervals for most data points include not only the predicted values but also zero; however, the good fit with predictions based on tangents is remarkably similar for both cluster orientations, strongly suggesting that the patterns are not obtained by chance (see also the results of Experiment 2, shown in Fig. 5; they show similar tendencies but not as clearly because clusters' position varied for different offsets, and with it also the orientation of the tangents). Thus it appears that, when judging the orientation between the dots that are displaced from a cluster centre, observers' judgments were biased towards the tangent nearest to the target dot. Judgments of dots placed at centroids were biased towards the steeper tangent (tangent A in Fig. 8), that is, away from horizontal. The only result clearly inconsistent with the tangent interpretation is for the +9 mm dot offset at the 30° cluster orientation. The tangent proposal predicts a zero bias, while the actual bias is significantly larger than zero, directed towards the centroids.

In this experiment, the absolute orientation between the clusters (10° and 30°) did not produce different patterns of results, while the results were different for 10° and 30° *dot* orientations in Experiment 2; the possible reason is that the corresponding range in cluster orientations was larger in the latter case.

5. General discussion

Morgan et al. (1990) suggested (a) that the visual system uses *indirect position coding* because such coding has a processing advantage in representing only a limited set of attributes (earlier proposed by Watt, 1988); (b) that the indirect route is *via centroids*, and (c) that this kind of position coding is *responsible for biases* in the Muller-Lyer and similar illusions because the local position of an element within the cluster is misjudged. Note that the latter two proposals do not necessarily follow from the first. Even if position coding is indirect, it does not have to be via centroids, and it in no way implies that there must be a bias. Therefore the absence of centroid bias in orientation judgments found in the present study does not represent evidence against indirect (or hierarchical) position coding in general. It does however show that centroid bias theory does not account for errors in judgments of orientation of elements belonging to different clusters, although most of the results concerning separation judgments were consistent with it.

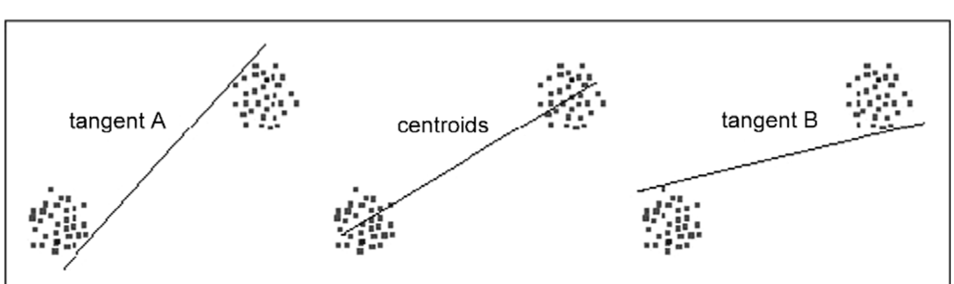

Fig. 7. Potential reference orientations for judgments of orientation between the elements belonging to different clusters (target dots are not shown). Rather than only a bias towards centroids, there may be a bias in orientation judgments towards other reference orientations, such as tangent A or B. The predicted pattern of errors is different in each case (see Fig. 8).

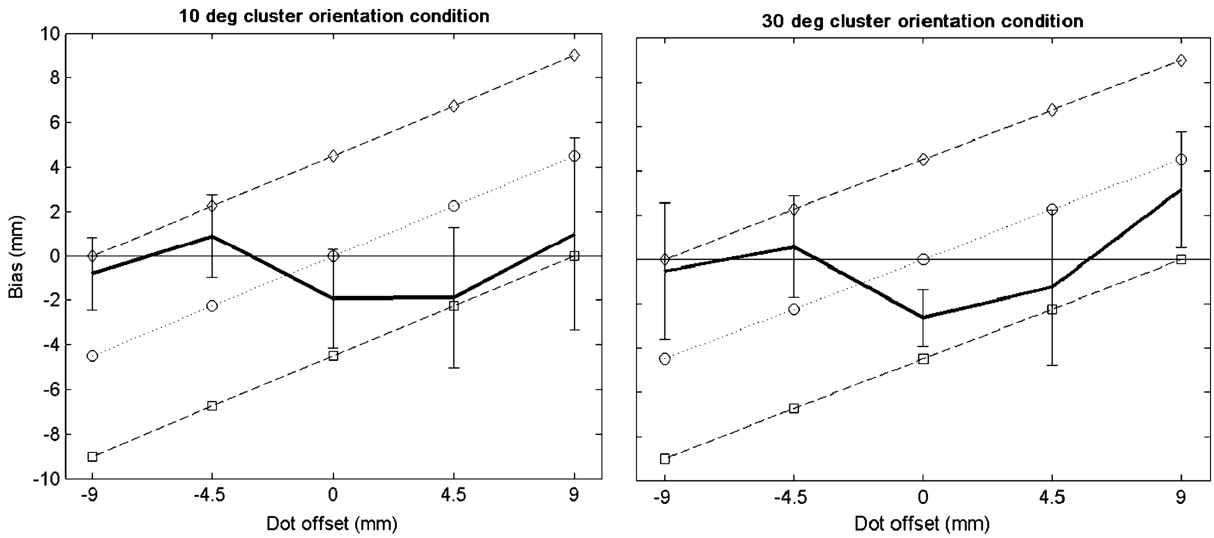

Fig. 8. Results of Experiment 3, group means and 95% confidence intervals ($n = 7$). Format is the same as in Fig. 5, such that positive offsets on the x-axis indicate that clusters were rotated clockwise relative to the dots, and positive data points indicate clockwise bias (note however that the two plots cannot be easily compared because stimuli were different: dots were in fixed positions in Experiment 2, and clusters' position varied, while the opposite was the case in Experiment 3). Dashed lines represent 1/4 of a maximal bias towards tangent A (squares) and tangent B (diamonds) as shown in Fig. 7, and dotted line with circular markers represents 1/4 of a maximal bias towards centroids.

Our results speak against the model because biases in perceived orientation were found both towards the centroid and away from it. Moreover, there was a bias in judgments—both with regards to their separation and orientation—concerning the elements placed *at the centroids* of their group. The theory is silent with regards to the latter bias, and it actually implies there should be none.

Although the centroid bias model cannot explain the present results, a modified version of indirect position coding (illustrated in Fig. 9, top) can accommodate them.

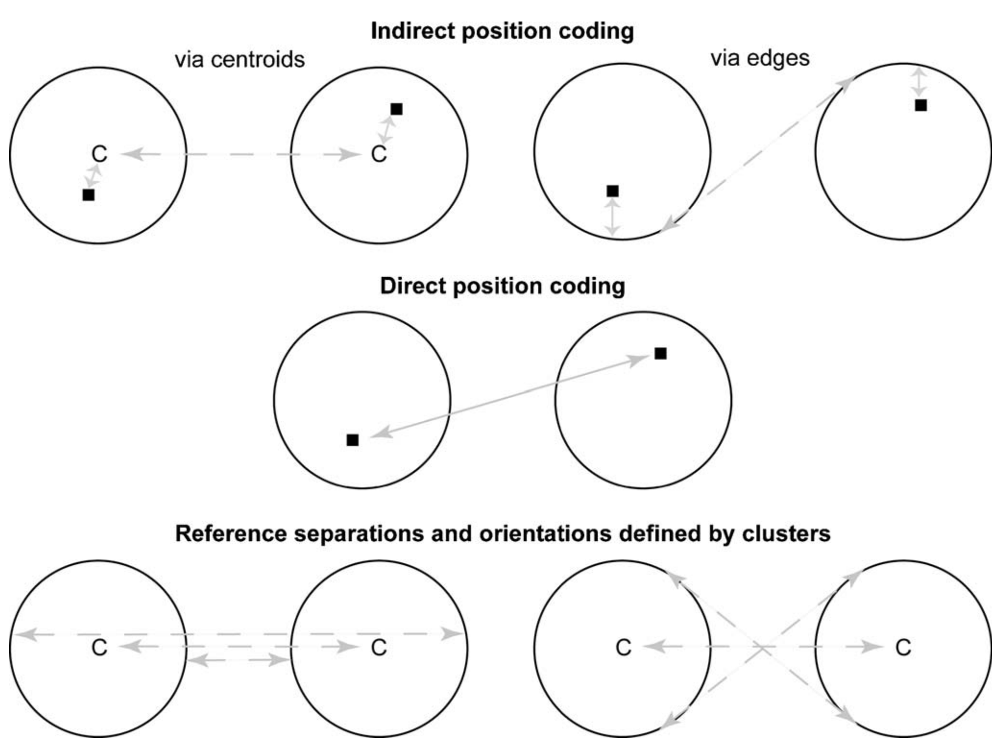

Fig. 9. Indirect and direct models of position coding and reference orientations and separations defined by pairs of clusters. Top, the illustration of indirect position coding based on centroids or edges. Each circle represents a cluster, and 'C', its centroid; rectangles represent elements of clusters. Position of each element is directly coded only relative to centroids or edges (short grey arrows), and position of centroids relative to each other (arrows with broken lines). Middle, the illustration of direct position coding of elements belonging to different clusters. Bottom, reference separations defined by a pair of clusters are between their inner and outer edges, and between the centroids. Reference orientations are specified by tangents to both clusters, and by the centroids.

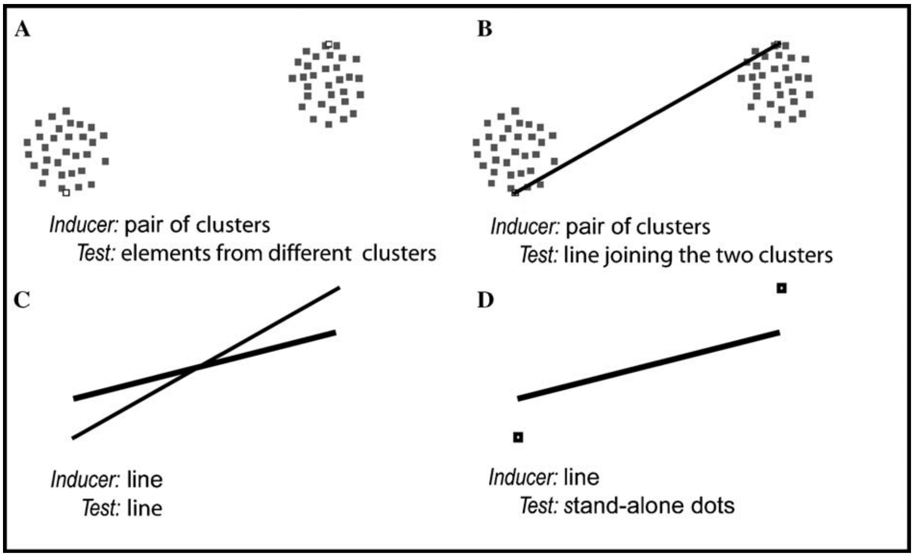

Fig. 10. Different types of inducing and test stimuli and their effect on orientation judgment. Indirect position coding explanation applies to clusters and their elements, illustrated in (A). According to this explanation, biases are due to the error in judgment of local position (within the cluster). It cannot apply to the stimuli shown in other panels because judgment does not concern elements belonging to different clusters. If future research shows that similar biases occur in each case (A–D), a more parsimonious explanation should be sought that covers them all.

The main modification required is that the indirect route involves edges rather than only centroids, given that we found bias towards the gap between the clusters in separation judgments (Experiment 1) and towards the tangents in orientation judgments (Experiments 2 and 3). The efficiency in position coding can also be achieved if edges of objects rather than their centroids are used as a reference; besides, the size of a gap or distance between the edges of neighboring objects is important in action—as when we need to reach or pass between objects. The indirect coding model should also allow that different indirect routs may be used even when they concern the same pair of objects, depending on which (route) is the closest to the orientation to be judged (as the results of Experiment 3 suggest).

However, the results are also consistent with the alternative, *direct position coding* model (illustrated in Fig. 9, middle). The direct coding model, as the name suggests, states simply that the relative position between elements of different clusters is directly represented. This model also requires additional assumptions to explain the bias, such as assimilation or contrast (repulsion) effects between the test separation or orientation and separations and orientations in the inducer (see Fig. 9, bottom).

Our results do not allow us to distinguish between the two models (modified indirect coding, and direct coding) which both give only a post hoc explanation of biases. In both cases, long-range orientations and separations defined by the pair of clusters influence judgments concerning the elements of those clusters. The indirect model does not explain why there should be local error in position coding in the first place, and the direct coding model does not explain why assimilation or repulsion should occur. Nonetheless, the direct coding model has one advantage: it is simpler, because it does not assume that clusters and elements represent a special case in perception of relative position. It does not distinguish between different stimulus types—clusters, lines or edges, or a combination thereof (see Fig. 10)—and allows for the possibility that similar mechanisms apply in all these cases, including the origin of biases. This means that biases should also be similar, and whether they are is an empirical question. We presently know that lines of different orientations interact creating a bias (e.g., Dakin, Williams, & Hess, 1999; Tyler & Nakayama, 1984), and that the same happens with implicit lines defined by clusters and their elements (present study). However, the results cannot be directly compared because the orientations and methods used in these studies were different; it is a matter for future research to compare biases across the range of stimulus types.

References

Binet, A. (1895). La mesure des illusions visuelles chez les enfants. *Review Philosophique, 40*, 11–25.

Dakin, S., Williams, C., & Hess, R. (1999). The interaction of first- and second-order cues to orientation. *Vision Research, 39*, 2867–2884.

Erlebacher, A., & Sekuler, R. (1974). Perceived length depends on exposure duration: Straight lines and Muller–Lyer illusion. *Journal of Experimental Psychology, 103*, 724–728.

Fisher, G. H. (1968). An experimental & theoretical appraisal of the inappropriate size-depth theories of illusions. *British Journal of Psychology, 59*, 373–383.

Gillam, B., & Chambers, D. (1985). Size and position are incongruous: Measurements on the Muller-Lyer figure. *Perception and Psychophysics, 37*, 549–556.

Gullberg, J. (1997). *Mathematics: From the birth of numbers*. W.W. Norton and Co.

Harris, J., & Morgan, M. (1993). Stereo and motion disparities interfere with positional averageing. *Vision Research, 33*(3), 309–312.

Heymans, G. (1896). Quantitative Untersuchungen über das" optische Paradoxen". *Zeitschrift für Psychology, 9*, 221–255.

Morgan, M., & Glennerster, A. (1991). Efficiency of locating centres of dot-clusters by human observers. *Vision Research, 31*(12), 2075–2083.

Morgan, M., Hole, G., & Glennerster, A. (1990). Biases and sensitivities in geometrical illusions. *Vision Research, 30*(11), 1793–1810.

Tyler, C., Nakayama, K., 1984. Size interactions in the perception of orientation. In L. Spillmann, B.R. Wooten, (Eds.), Sensory Experience, Adaptation and Perception, pp. 529–546.

Watt, R. J. (1988). *Visual processing: Computational, psychophysical and cognitive research.* Sussex: Erlbaum.

Woodworth, R. (1945). *Psychology*. London: Methuan & Co Ltd.